UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) CR 87-05	5. MONITORING ORGANIZATION REPORT NUMBER(S) CR 87-05
6a. NAME OF PERFORMING ORGANIZATION Science Applications International Corp. 6b. OFFICE SYMBOL *(If applicable)*	7a. NAME OF MONITORING ORGANIZATION Naval Environmental Prediction Research Facility
6c. ADDRESS *(City, State, and ZIP Code)* 205 Montecito Avenue Monterey, CA 93940	7b. ADDRESS *(City, State, and ZIP Code)* Monterey, CA 93943-5006
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Commander, Naval Oceanography Command 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00228-84-D-3187
8c. ADDRESS *(City, State, and ZIP Code)* NSTL, MS 39529-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO. DN656794

11. TITLE *(Include Security Classification)*
Severe Weather Guide - Mediterranean Ports - 5. Cagliari (U)

12. PERSONAL AUTHOR(S)
Englebretson, Ronald E. (LCDR, USN, Ret.) and Gilmore, Richard D. (CDR, USN, Ret.)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
Final	FROM 9/13/84 TO 11/1/86	1988, March	64

16. SUPPLEMENTARY NOTATION
Funding Source: O & M, N-1

17. COSATI CODES			18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
FIELD	GROUP	SUB-GROUP	Storm haven; Cagliari port; Mediterranean meteorology; Mediterranean oceanography
04	02		

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This handbook for the port of Cagliari, one in a series of severe weather guides for Mediterranean ports, provides decision-making guidance for ship captains whose vessels are threatened by actual or forecast strong winds, high seas, restricted visibility or thunderstorms in the port vicinity. Causes and effects of such hazardous conditions are discussed. Precautionary or evasive actions are suggested for various vessel situations. The handbook is organized in four sections for ready reference: general guidance on handbook content and use; a quick-look captain's summary; a more detailed review of general information on environmental conditions; and an appendix that ptovides oceanographic information.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Perryman, Dennis C., contract monitor	22b. TELEPHONE *(Include Area Code)* (408) 647-4709 / 22c. OFFICE SYMBOL O&M,N-1

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

AN (1) AD-A199 387
FG (2) 040200
CI (3) (U)
CA (5) SCIENCE APPLICATIONS INTERNATIONAL CORP MONTEREY CA
TI (6) Severe Weather Guide - Mediterranean Ports. 5. Cagliari.
TC (8) (U)
DN (9) Final rept. 13 Sep 84-1 Nov 86,
AU (10) Englebretson, Ronald E.
AU (10) Gilmore, Richard D.
RD (11) Mar 1988
PG (12) 66p
CT (15) N00228-84-D-3187
RN (18) NEPRF-CR-87-05
RC (20) Unclassified report
NO (21) See also Number 6, AD-A199 386.
DE (23) *PORTS, (FACILITIES), DECISION MAKING, HANDBOOKS, HAZARDS, LIMITATIONS, MEDITERRANEAN SEA, OCEANOGRAPHIC DATA, THUNDERSTORMS. VISIBILITY, WIND.
DC (24) (U)
AB (27) This handbook for the port of Cagliari, one in a series of severe weather guides for Mediterranean ports, provides decision-making guidance for ship captains whose vessels are threatened by actual or forecast strong winds, high seas, restricted visibility or thunderstorms in the port vicinity. Causes and effects of such hazardous conditions are discussed. Precautionary or evasive actions are suggested for various vessel situations. The handbook is organized in four sections for ready reference: general guidance on handbook content and use; a quick-look captain's summary; a more detailed review of general information on environmental conditions; and an appendix that provides oceanographic information. (fr)
AC (28) (U)
DL (33) 01
SE (34) F
CC (35) 417277

#

Naval Environmental Prediction Research Facility
Monterey, CA 93943-5006
Contractor Report CR 87-05 March 1988

SEVERE WEATHER GUIDE MEDITERRANEAN PORTS

5. CAGLIARI

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CONTENTS

FOREWORD

This handbook on Mediterranean Ports was developed as part of an ongoing effort at the Naval Environmental Prediction Research Facility to create products for direct application to Fleet operations. The research was conducted in response to Commander Naval Oceanography Command (CNOC) requirements validated by the Chief of Naval Operations (CNO).

As mentioned in the preface, the Mediterranean region is unique in that several areas exist where local winds can cause dangerous operating conditions. This handbook will provide the ship's captain with assistance in making decisions regarding the disposition of his ship when heavy winds and seas are encountered or forecast at various port locations.

Readers are urged to submit comments, suggestions for changes, deletions and/or additions to NOCC, Rota with a copy to the oceanographer, COMSIXTHFLT. They will then be passed on to the Naval Environmental Prediction Research Facility for review and incorporation as appropriate. This document will be a dynamic one, changing and improving as more and better information is obtained.

M. G. SALINAS
Commander, U.S. Navy

PORT INDEX

The following is a tentative prioritized list of Mediterranean Ports to be evaluated during the five-year period 1988-92, with ports grouped by expected year of the port study's publication. This list is subject to change as dictated by circumstances and periodic review.

1988 NO.	PORT
1	GAETA, ITALY
2	NAPLES, ITALY
3	CATANIA, ITALY
4	AUGUSTA BAY, ITALY
5	CAGLIARI, ITALY
6	LA MADDALENA, ITALY
7	MARSEILLE, FRANCE
8	TOULON, FRANCE
9	VILLEFRANCHE, FRANCE
10	MALAGA, SPAIN
11	NICE, FRANCE
12	CANNES, FRANCE
13	MONACO
14	ASHDOD, ISRAEL
15	HAIFA, ISRAEL
	BARCELONA, SPAIN
	PALMA, SPAIN
	IBIZA, SPAIN
	POLLENSA BAY, SPAIN
	VALENCIA, SPAIN
	CARTAGENA, SPAIN
	GENOA, ITALY
	LIVORNO, ITALY
	SAN REMO, ITALY
	LA SPEZIA, ITALY
	VENICE, ITALY
	TRIESTE, ITALY

1989	PORT
	SPLIT, YUGOSLAVIA
	DUBROVNIK, YUGOSLAVIA
	TARANTO, ITALY
	PALERMO, ITALY
	MESSINA, ITALY
	TAORMINA, ITALY
	PORTO TORRES, ITALY

1990	PORT
	BENIDORM, SPAIN
	ROTA, SPAIN
	TANGIER, MOROCCO
	PORT SAID, EGYPT
	ALEXANDRIA, EGYPT
	ALGIERS, ALGERIA
	TUNIS, TUNISIA
	GULF HAMMAMET, TUNISIA
	GULF OF GABES, TUNISIA
	SOUDA BAY, CRETE

1991	PORT
	PIRAEUS, GREECE
	KALAMATA, GREECE
	THESSALONIKI, GREECE
	CORFU, GREECE
	KITHIRA, GREECE
	VALETTA, MALTA
	LARNACA, CYPRUS

1992	PORT
	ANTALYA, TURKEY
	ISKENDERUN, TURKEY
	IZMIR, TURKEY
	ISTANBUL, TURKEY
	GOLCUK, TURKEY
	GULF OF SOLLUM

PREFACE

Environmental phenomena such as strong winds, high waves, restrictions to visibility and thunderstorms can be hazardous to critical Fleet operations. The cause and effect of several of these phenomena are unique to the Mediterranean region and some prior knowledge of their characteristics would be helpful to ship's captains. The intent of this publication is to provide guidance to the captains for assistance in decision making.

The Mediterranean Sea region is an area where complicated topographical features influence weather patterns. Katabatic winds will flow through restricted mountain gaps or valleys and, as a result of the venturi effect, strengthen to storm intensity in a short period of time. As these winds exit and flow over port regions and coastal areas, anchored ships with large 'sail areas' may be blown aground. Also, hazardous sea state conditions are created, posing a danger for small boats ferrying personnel to and from port. At the same time, adjacent areas may be relatively calm. A glance at current weather charts may not always reveal the causes for these local effects which vary drastically from point to point.

Because of the irregular coast line and numerous islands in the Mediterranean, swell can be refracted around such barriers and come from directions which vary greatly with the wind. Anchored ships may experience winds and seas from one direction and swell from a different direction. These conditions can be extremely hazardous for tendered vessels. Moderate to heavy swell may also propagate outward in advance of a storm resulting in uncomfortable and sometimes dangerous conditions, especially during tending, refueling and boating operations.

This handbook addresses the various weather conditions, their local cause and effect and suggests some evasive action to be taken if necessary. Most of the major ports in the Mediterranean will be covered in the handbook. A priority list, established by the Sixth Fleet, exists for the port studies conducted and this list will be followed as closely as possible in terms of scheduling publications.

RECORD OF CHANGES

CHANGE NUMBER	DATE OF CHANGE	DATE ENTERED	PAGE NUMBER	ENTERED BY

1. GENERAL GUIDANCE

1.1 DESIGN

This handbook is designed to provide ship captains with a ready reference on hazardous weather and wave conditions in selected Mediterranean harbors. Section 2, the captain's summary, is an abbreviated version of section 3, the general information section intended for staff planners and meteorologists. Once section 3 has been read, it is not necessary to read section 2.

1.1.1 Objectives

The basic objective is to provide ship captains with a concise reference of hazards to ship activities that are caused by environmental conditions in various Mediterranean harbors, and to offer suggestions for precautionary and/or evasive actions. A secondary objective is to provide adequate background information on such hazards so that operational forecasters, or other interested parties, can quickly gain the local knowledge that is necessary to ensure high quality forecasts.

1.1.2 Approach

Information on harbor conditions and hazards was accumulated in the following manner:

A. A literature search for reference material was performed.

B. Cruise reports were reviewed.

C. Navy personnel with current or previous area experience were interviewed.

D. A preliminary report was developed which included questions on various local conditions in specific harbors.

E. Port/harbor visits were made by NEPRF personnel; considerable information was obtained through interviews with local pilots, tug masters, etc; and local reference material was obtained (See section 3 references).

F. The cumulative information was reviewed, combined, and condensed for harbor studies.

1.1.3 Organization

The Handbook contains two sections for each harbor. The first section summarizes harbor conditions and is intended for use as a quick reference by ship captains, navigators, inport/at sea OOD's, and other interested personnel. This section contains:

A. a brief narrative summary of environmental hazards,

B. a table display of vessel location/situation, potential environmental hazard, effect-precautionary/evasion actions, and advance indicators of potential environmental hazards,

C. local wind wave conditions, and

D. tables depicting the wave conditions resulting from propagation of deep water swell into the harbor.

The swell propagation information includes percent occurrence, average duration, and the period of maximum wave energy within height ranges of greater than 3.3 feet and greater than 6.6 feet. The details on the generation of sea and swell information are provided in Appendix A.

The second section contains additional details and background information on seasonal hazardous conditions. This section is directed to personnel who have a need for additional insights on environmental hazards and related weather events.

1.2. CONTENTS OF SPECIFIC HARBOR STUDIES

This handbook specifically addresses potential wind and wave related hazards to ships operating in various Mediterranean ports utilized by the U.S. Navy. It does not contain general purpose climatology and/or comprehensive forecast rules for weather conditions of a more benign nature.

The contents are intended for use in both pre-visit planning and in situ problem solving by either mariners or environmentalists. Potential hazards related to both weather and waves are addressed. The oceanographic information includes some rather unique information relating to deep water swell propagating into harbor shallow water areas.

Emphasis is placed on the hazards related to wind, wind waves, and the propagation of deep water swell into the harbor areas. Various vessel locations/situations are considered, including moored, nesting, anchored, arriving/departing, and small boat operations. The potential problems and suggested pre-cautionary/evasive actions for various combinations of environmental threats and vessel location/situation are provided. Local indicators of environmental hazards and possible evasion techniques are summarized for various scenarios.

CAUTIONARY NOTE: In September 1985 Hurricane Gloria raked the Norfolk, VA area while several US Navy ships were anchored on the muddy bottom of Chesapeake Bay. One important fact was revealed during this incident: Most all ships frigate size and larger dragged anchor, some more than others, in winds of over 50 knots. As winds and waves increased, ships 'fell into' the wave troughs, BROADSIDE TO THE WIND and become difficult or impossible to control.

This was a rare instance in which several ships of recent design were exposed to the same storm and much effort was put into the documentation of lessons learned. Chief among these was the suggestion to evade at sea rather than remain anchored at port whenever winds of such intensity were forecast.

2. CAPTAIN'S SUMMARY

Cagliari Harbor is located on the south coast of the Italian island of Sardinia on the northwest side of the Gulf of Cagliari (Golfo di Cagliari), (Figure 2-1).

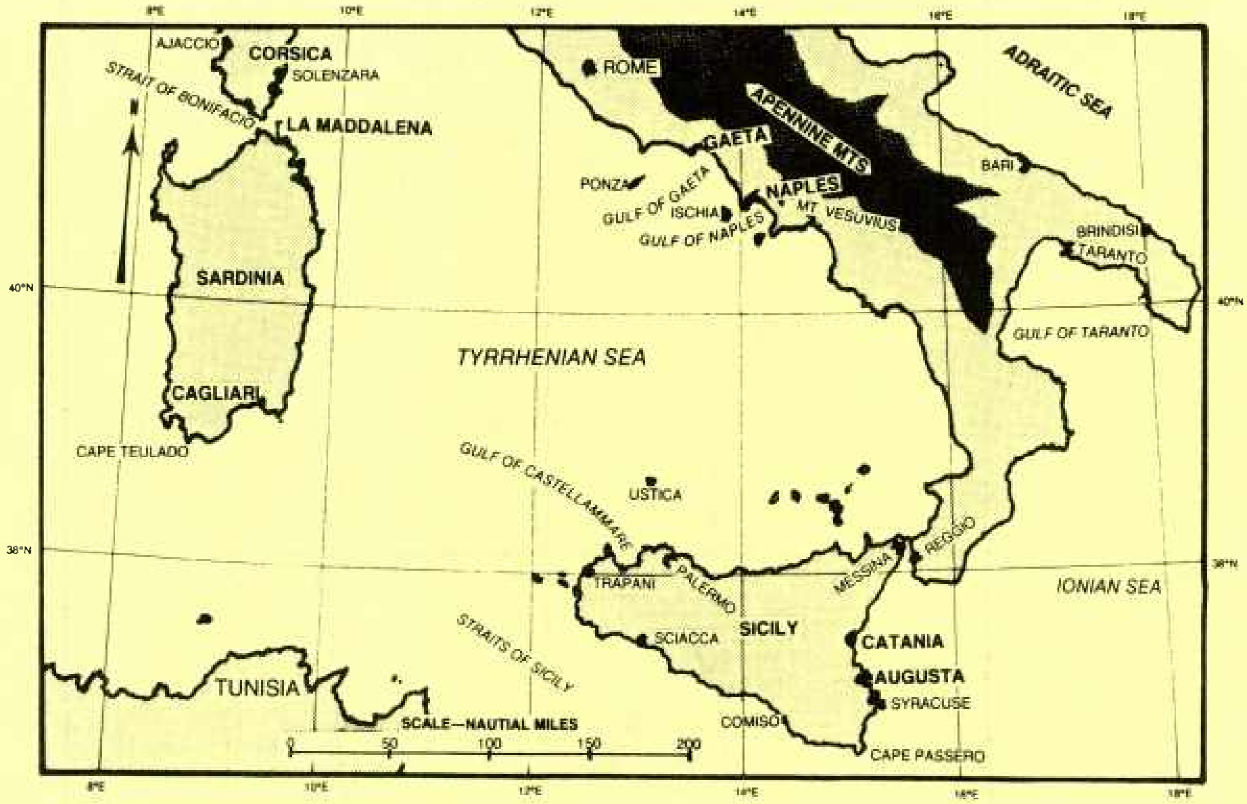

Figure 2-1. Ports of Italy, Sicily, and Sardinia.

Two anchorage areas have been selected for Cagliari (Figure 2-3). Point 1 is 4-5 n mi southeast of the enclosed harbors, bearing 170° from Scogtio Sant'Elia. Point 2 is about 8 n mi due south of the enclosed harbors east of Sarroch.

The designated anchorages are exposed to winds and waves of the open sea. Strong southeasterly winds of force 7 (28 to 33 kt) pose the greatest threat to anchored vessels due to the long fetch and associated high swell. Strong northwesterly winds of force 7 (28 to 33 kt with gusts to 70 kt) can cause vessels to drag anchor, but the short fetch to the northwest limits wave problems to small craft operations.

Tanker crews at Sarroch sometimes call the weather office at the Cagliari Airport to check on the local weather forecast when they start to feel swell motion in the anchorage. The onset of such swell motion is an indicator of impending southeasterly winds since the long-period swell often travels faster than the wind field that generated it, and arrives ahead of the winds.

Tides are slight, about 1 ft (0.3 m) maximum.

Currents are generally wind driven, set with the wind, and are weak. However, with strong northwest winds a 4 to 5 kt east current has been reported off Isola Dei Cavoli (Figure 2-3).

Specific hazardous atmospheric conditions, vessel situations, and suggested precautionary/evasion action scenarios are summarized in Table 2-1. Hazards for both inport and at anchorage are addressed.

TABLE 2-1. Summary of hazardous environmental conditions for the Port of Cagliari, Italy.

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
1. NW'ly wind - Primary cause is Mistral from Gulf of Lion. * Strongest wind at Cagliari, it funnels to Port area through Campidano Valley. * Strongest in late winter/early spring, wind velocities may reach 30-35 kts with gusts to 60-70 kts. * Weakest in summer.	Advance warning * Approximately 24 hours after mistral starts in Gulf of Lion. * Approximately 5 to 7 hours after orographically induced cumulus clouds are observed over the mountains west of the Port. Duration * Predominant wind at Cagliari - 170 days per year. * Strong winds will persist as long as Mistral conditions last.	(1) Moored.	(a) Wind may tend to force vessels off moorings. * Lines may need to be doubled.
		(2) Anchored.	(a) Wind may cause anchor dragging. * Two anchors may be required. * A strong event may require evasion to E coast of Sardinia N of Cape Ferrato.
		(3) Arriving/departing.	(a) Evolution should be completed before wind onsets or after it abates. * Limited maneuvering room in inner harbor.
		(4) Small boat operations.	(a) Wind raises a chop in the entrance to outer harbor and outside Nuovo Molo di Levante. * Boating to/from anchorage may be curtailed until conditions abate.
2. SE'ly wind/seas - Caused by Scirocco or low transiting south of Sardinia. * Produces worst swell at anchorages. * Most common during autumn. * Maximum velocities about 30 kts. * Swell reflects off breakwater to west of harbor, causing chop near harbor entrance. * May be accompanied by rain turned red by sand and dust in atmosphere.	Advance Warning * Good visibility between the Port and Sarroch anchorage provides 24-hour warning. * The sun "turning white" during winter indicates SE winds and rain will occur within 24 hours. * Cloud buildup on mountains west of Sarroch indicates possible forthcoming SE winds/seas. * Long period swell felt in tankers at anchorage off Sarroch are an indicator of impending southeasterly winds. Duration * Occurs about 60 days per year at Cagliari. * Strong winds usually last 24 to 36 hours before changing to NW.	(1) Moored.	(a) Inner harbor is affected only by wind, which may tend to force vessels off moorings. * Lines may need to be doubled. (b) Swell affects only outer harbor entrance and waters outside Nuovo Molo di Levante. * Minimal effect in inner harbor.
		(2) Anchored.	(a) Force of wind/swell may cause vessels to drag anchor. * Two anchors may be required. * Strong event may require evasion to the protected waters of the Gulf of Palmas (Golfo de Palmas), about 40 n mi W of Cagliari.
		(3) Arriving/departing.	(a) Evolutions should be completed prior to wind onset or delayed until winds abate. * Winds will affect ship handling in inner harbor. * Swell may make anchoring inadvisable.
		(4) Small boat operations.	(a) Winds/seas create hazardous boating conditions in harbor entrance and outside Nuovo Molo di Levante. * Boating to/from anchorage may be curtailed. * Boating in inner harbor minimally affected.
3. Tropical cyclones - Although uncommon, tropical cyclones have been observed in the Mediterranean basin. * Most likely in late summer/autumn but may occur in any month. * Storm track is difficult to forecast accurately. Mariners must give wide berth to forecast track.	Advance warning * High, thin clouds in cyclonically spiralling, gradually thickening bands. * Unexplained long-period swell approaching from the southern semicircle.	(1) Moored.	(a) Vessels should put to sea and evade storm.
		(2) Anchored.	(a) Vessels should put to sea and evade storm.
		(3) Arriving/departing.	(a) Vessels should put to sea or stay at sea and evade storm.
		(4) Small boat operations.	(a) Curtail all small boat operations prior on onset of wind. * Hoist small craft out of the water and secure well above high tide line, or * If on ship, hoist small craft out of the water and secure on deck.

Table 2-2 provides the height ratio and direction of shallow water waves to expect at points 1 and 2 (Figure 2-3) when the deep water wave conditions are known.

The Cagliari Point 1 conditions are found by entering Table 2-2 with the forecast or known deep water wave direction and period. The height is determined by multiplying the deep water height (8 ft) by the ratio of shallow to deep height (.4).

Example: Use of Table 2-2 for Cagliari Point 1.
Deep water wave forecast as provided by a forecast center or a reported/observed deep water wave condition:
8 feet, 10 seconds, from 210°.
The expected wave condition at Cagliari. Point 1 as determined from Table 2-2:
3 feet, 10 seconds, from 180°.

NOTE: Wave periods are a conservative property and remain constant when waves move from deep to shallow water, but speed, height, and steepness change.

Table 2-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 2-3 for location of points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

CAGLIARI POINT 1:

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	100° .7	105° .6	110° .7	110° .4	115° .4	120° .4
120°	120° .9	120° .8	120° .8	125° .7	125° .6	125° .6
150°	150° .9	150° .8	145° .7	140° .7	140° .6	140° .6
180°	180° .9	175° .8	170° .6	160° .6	160° .7	150° .8
210°	190° .6	190° .5	180° .4	170° .3	165° .3	160° .2
240°	180° .2	180° .2	180° .3	175° .3	170° .4	165° .3

CAGLIARI POINT 2:

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	090° .9	090° .8	095° .7	100° .5	100° .5	100° .5
120°	120° 1.0	120° .9	120° .9	120° .8	120° .8	120° .8
150°	150° 1.0	150° .9	145° .8	140° .7	140° .8	135° .8
180°	180° 1.0	175° .8	170° .8	160° .6	155° .5	150° .5
210°	210° .7	200° .5	190° .4	185° .5	180° .5	160° .3
240°	180° .2	180° .2	205° .2	180° .2	170° .3	170° .4

The local wind generated wave conditions for the anchorage area identified as point 1 (Figure 2-3) are given in Table 2-3. All heights refer to the significant wave height (average of the highest 1/3 waves). Enter the local wind speed and direction in this table to obtain the minimum duration in hours required to develop the indicated fetch limited sea height and period. The time to reach fetch limited height is based on an initial flat ocean. When starting from a pre-existing wave height, the time to fetch limited height will be shorter.

Table 2-3. Gulf of Cagliari Point 1. Local wind waves for fetch limited conditions related to Point 1 (based on JONSWAP model).

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
SW 12 n mi	2-3/4 2	3/4 2	3-4/4 1-2	4-5/4-5 2	5-6/5 2
NW 7 n mi	<2 ft	2/3 1	3/4 1	3-4/4 1	4/4 1
N 4 n mi	<2 ft	<2 ft	2/3 1	2-3/3 1	3/3 1
E 10 n mi	2/3-4 1-2	3/3-4 2	3-4/4 2	4/4-5 1-2	5/5 1-2
SE* 16 n mi	3/4 3	3-4/4-5 2	4/5 2	4-5/5 2	6/5 2

* Southwest flow over the open sea backs to southeast over the Gulf of Cagliari. The maximum fetch resulting from such a wind pattern would be about 16 n mi. Wind waves would be generated over that distance and combine with the deep water swell which changes from southwest to south over the Gulf (see Table 2-2).

Example:

To the northwest (315°) there is about a 7 n mi fetch (Figure 2-3). Given a northwest wind at 36 kt, the sea will have reached 3-4 feet with a period of 4 seconds within 1 hour. Wind waves will not grow beyond this condition unless the wind speed increases or the direction changes to one over a longer fetch length. If the wind waves are superimposed on deep water swell, the combined height may change in response to changing swell conditions. Wind wave directions are assumed to be the same as the wind direction.

Combined Wave heights are obtained by finding the square root of the sum of the squares of the swell and wind wave heights.

Example: Swell 10 ft, wind wave 5 ft.

$$\sqrt{10^2 + 5^2} = \sqrt{100 + 25} = \sqrt{125} \approx 11.2 \text{ ft}$$

Note: Increase over larger height is small. If both heights were equal, combined height would increase by a factor of 1.4. If one is half of the other, as in the example, increase over the larger of the two is by a factor of 1.12.

Climatological factors of shallow water waves, as described by percent occurrence, average duration, and period of maximum energy (period at which the most energy is focused for a given height), are given in Table 2-4. See Appendix A for discussion of wave spectrum and energy distribution. These data are provided by season for two ranges of heights: greater than 3.3 feet and greater than 6.6 feet.

Table 2-4. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 feet and greater than 6.6 feet by climatological season.

CAGLIARI POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	20	10	7	11
Average Duration (hrs)	13	13	10	10
Period Max Energy(sec)	12	8	8	8
>6.6 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	5	2	1	1
Average Duration (hrs)	8	6	8	8
Period Max Energy(sec)	12	12	12	12*
CAGLIARI POINT 2:	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**
>3.3 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	20	10	7	13
Average Duration (hrs)	13	11	12	11
Period Max Energy(sec)	9-10	8-9	8	8
>6.6 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	2	1	1
Average Duration (hrs)	9	8	6	9
Period Max Energy(sec)	10	12	12	9-10

* The 12 second period shows a sharp peak in the wave climatology energy values. This indicates that for wave heights over 6.6 feet, waves with a 12 second period have a high frequency of occurrence. This pattern is known as "short crested conditions" (see page A-3 of Appendix A for explanation of "short crested conditions").

SEASONAL SUMMARY OF HAZARDOUS WEATHER CONDITIONS

WINTER (November thru February):

* Frequent (especially February) strong northwesterlies due to Mistral, generally 30-35 kt gusting to 60-70 kt.
* Mistral causes high waves at anchorage, moderate chop in harbor.
* High waves in harbor caused by strong southeasterlies due to Scirocco or low in Strait of Sicily.
* Dangerous wind chill infrequent but can occur when cold temperature combines with strong wind.

SPRING (March thru May):

* Early spring conditions are like winter.
* Sea breeze occurs on warmest days.

SUMMER (June thru September):

* Sea breeze daily occurrence.

AUTUMN (October):

* Short transition season with winter weather returning by end of month.
* Scirocco common in autumn and rain associated with it may be red due to dust/sand transported from Africa.

NOTE: For more detailed information on hazardous weather conditions see previous Summary Table in this section and Hazardous Weather Summary in Section 3.

3. GENERAL INFORMATION

This section expands on the material in the Captain's Summary. Figures and Tables are repeated with a continuation of numbering. Paragraph 3.5 provides a general discussion of hazards and Table 3-5 provides a summary of hazards and actions by season.

3.1 Geographic Location

The Port of Cagliari is located at 39°13'N 09°07'E on the south coast of the Italian island of Sardinia on the northwest side of the Gulf of Cagliari (Golfo di.Cagliari), (Figure 3-1).

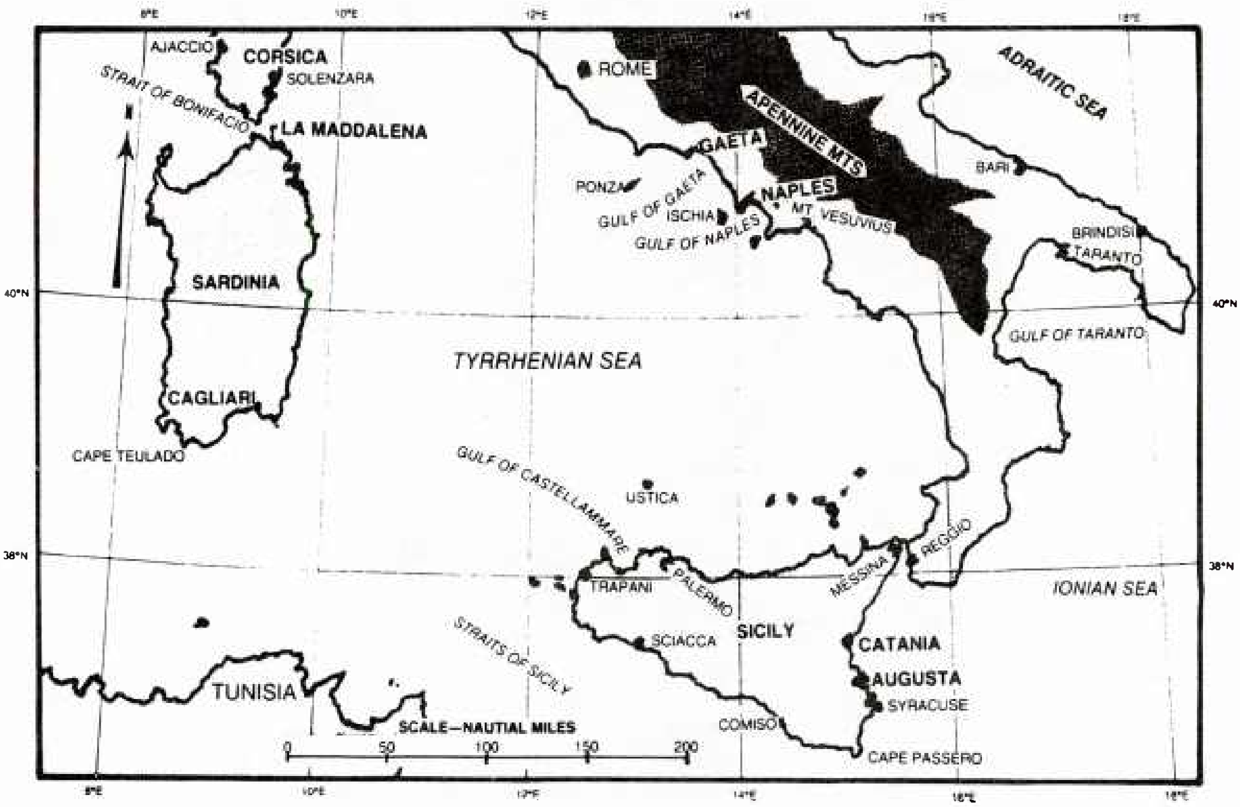

Figure 3-1. Ports of Italy, Sicily, and Sardinia.

The Gulf of Cagliari is exposed to winds and waves from the southeast quadrant and to northwest winds funneled through the Campidano Valley (Figure 3-2). Vessels desiring to avoid strong northwesterly winds can move east around Cape Carbonara and northward beyond Cape Ferrato. The Gulf of Palmas (Golfo di Palmas), located about 40 n mi west of Cagliari, offers good protection from southeasterly winds and waves.

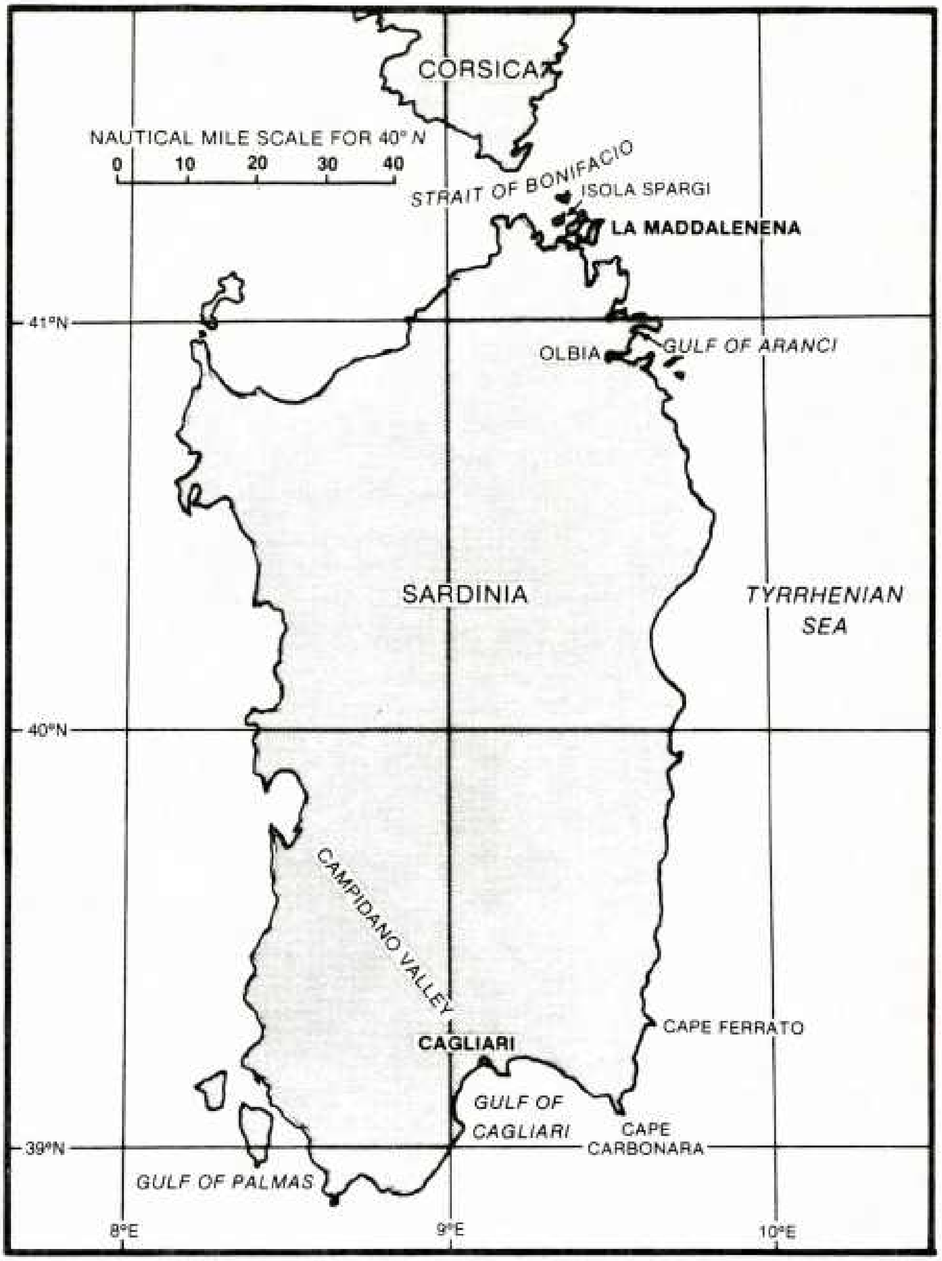

Figure 3-2. Gulf of Cagliari

The Port of Cagliari consists of inner and outer harbors. The artificial outer harbor is protected by two extensive breakwaters: Nuovo Molo di Ponente which forms and protects the west side of the harbor, and Nuovo Molo di Levante which forms and protects the south side (Figure 3-3). The inner harbor is protected by Vecchio Molo di Levante and Molo Sebaudo. Cagliari is the largest commercial port on Sardinia and the capital of the island.

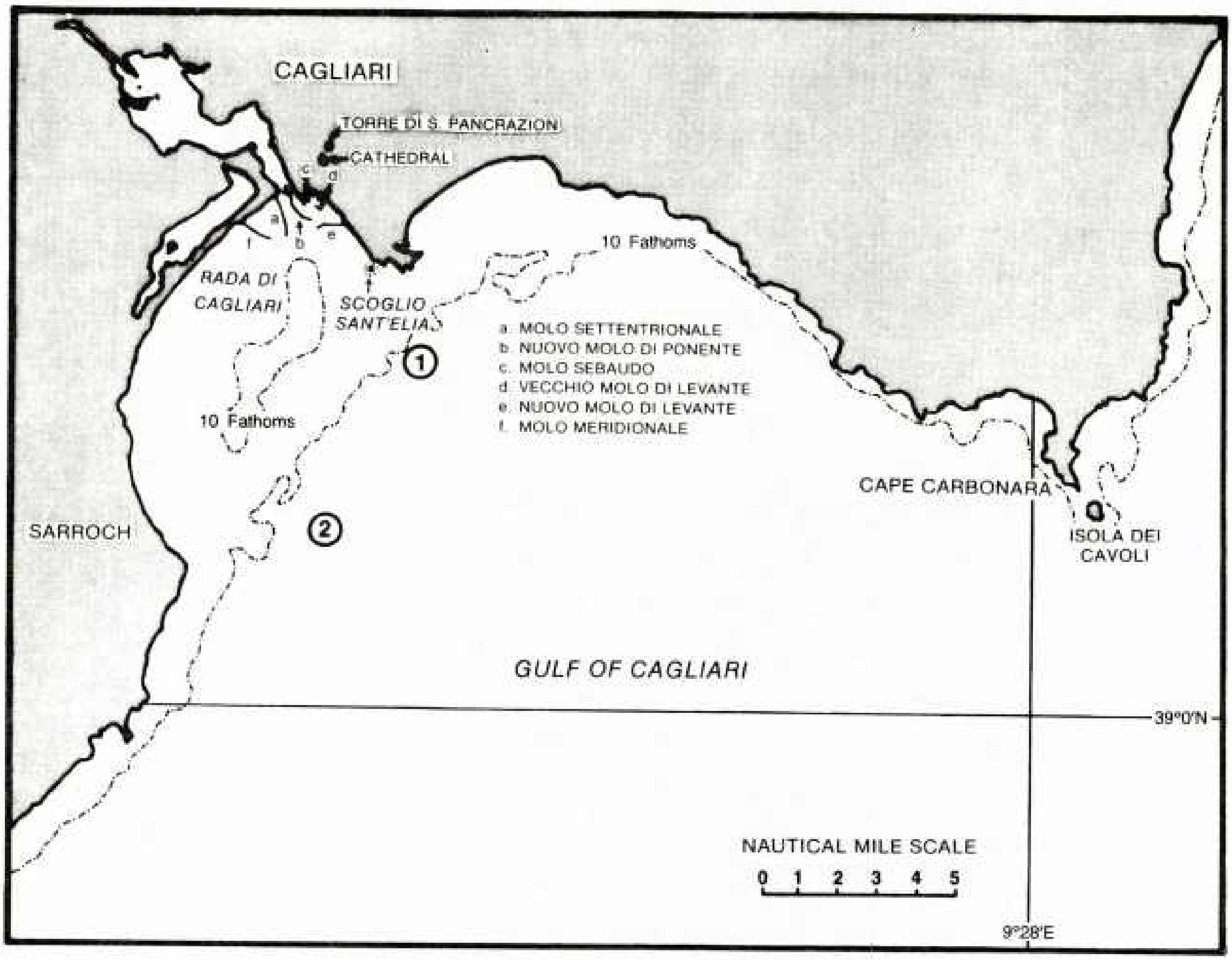

Figure 3-3. Port of Cagliari

3.2 Qualitative Evaluation of the Port of Cagliari

The Port of Cagliari is situated at the southeast end of the Campidano Valley, a long rift in the mountainous terrain of Sardinia. Elevations of the terrain bordering the valley range from 2,000 to 3,500 ft (610 to 1,067 m) on the northeast side to over 4,000 ft (1,219 m) on the southwest side. The configuration of the valley is largely responsible for the prevailing northwesterly winds (170 days per year) at Cagliari, and serves as a funnel to direct strong Mistral winds to the Port.

The inner harbor is sheltered and considered safe. The outer harbor is well protected, but southeasterly swell reflects off of the face of a breakwater which protects a new industrial harbor (no U.S. military ships allowed) located west of the primary harbor, and enters the outer harbor. The reflected swell is not a significant bother to ships but can create problems for small boats going to or from the anchorage. The bottom of the harbor offers moderate holding ground.

While smaller vessels utilize the protected waters inside the breakwaters, large vessels must anchor out. The primary anchorage (Point 1) is located on radial 170° about 2 to 3 n mi from Scoglio Sant' Elia (Figure 3-3) in a depth of 82 to 98 ft (25 to 30 m). Holding is generally good on a sand bottom. Commercial tankers anchor (Point 2) near Sarroch south of 39°04'N from the coast to 09°10'E in depths of 115 to 131 ft (35 to 40 m). Both anchorages are exposed to southeasterly wind and waves. Anchorage can be taken in 60 ft (18.3 m) of water with good holding ground in Rada di Cagliari (U. S. Navy, 1983).

3.3 Currents and Tides

Currents near Cagliari are wind driven and mostly weak. The current sets east with a northwest wind and west with a southeast wind. A strong northwest wind is reported to cause a 4 to 5 kt current off of Isola Dei Cavoli (Figure 3-3). According to U. S. Navy, 1983, an east current, "particularly noticeable with winds from the northwest quadrant and after heavy rain carries sea weed into the harbor." Tides are slight, with a spring rise of only about 1 ft (30 cm). The tidal rise doesn't exceed 2 ft even when augmented by onshore winds.

3.4 Visibility

Visibility conditions at Cagliari are rarely bad, but are best under northwesterly flow and worst under southeasterly flow. When occurring, restricted visibility is most common during early morning hours.

3.5 Hazardous Conditions

A seasonal summary of known environmental hazards that may be encountered in the Port of Cagliari follows.

A. Winter (November through February)

The winter season brings frequent strong northwesterly winds to the Port of Cagliari as Mistral winds blow from the Gulf of Lion across the western Mediterranean Sea to Sardinia. Most frequent in February (Brody and Nestor, 1980), the winds reach the Port as 30 to 35 kt northwesterlies with gusts as strong as 60 to 70 kt. The winds cause only minor problems in the harbor, but anchor dragging is possible for anchored vessels. Because the wind is offshore, the fetch is severely limited and the effect on the sea surface is limited to a chop. The chop can, however, affect small craft operations in the harbor and jeopardize small boat runs to and from the anchorage. The wind is strongest when a low pressure system moves across the Gulf of Genoa.

Strong southeasterly winds (to 30 kt) pose a greater hazard to the Port of Cagliari. They can be caused by a Scirocco or a low pressure system in the Strait of Sicily but, in either case, because of the long fetch area, can generate southeasterly swell which propagates to and adversely affects the Port. The swell is highest near Sarroch, but also affects the anchorage south of Scoglio Sant' Elia. Southeasterly swell tends to reflect off of the face of the breakwater which protects the east side of the new commercial port and enters the outer harbor of the primary port area through the west-facing harbor entrance. The reflected waves create hazardous conditions for small boats. When the winds are caused by a low in the Strait of Sicily, they may be accompanied by rain and thunderstorms produced by orographic lifting over the mountains of Sardinia. Southeasterly winds occur about 60 days per year, usually lasting about 24 to 36 hours before returning to northwesterly, except that a strong Scirocco event may last longer.

There are generally no other strong wind effects at Cagliari. Southwesterly winds turn to southeast as they cross the Gulf of Cagliari, and usually cause no problems at the Port. The harbor is protected from southwesterly swell.

Visibility is mostly good during winter, with fog occurring occasionally during early morning hours early in the season.

Precipitation is common during winter as it is the wettest season of the year at Cagliari.

Winter temperatures normally range from about 43°F (6°C) to 57°F (14°C). The extreme range for the season, based on a 20-year record, spans 25°F (-4°C) to 72°F (22°C). While the temperatures do not appear cold by many standards, the wind chill (temperature combined with wind) can adversely affect personnel working on weather decks without proper protection. (Table 3-1 can be used to determine wind chill for various temperature and wind combinations.)

Table 3-1. Wind Chill. The cooling power of the wind expressed as "Equivalent Chill Temperature" and the danger of freezing exposed flesh (adapted from Miller and Thompson, 1970).

Wind Speed		Cooling Power of Wind expressed as "Equivalent Chill Temperature"								
Knots	MPH	Temperature (°F)								
Calm	Calm	50	45	40	35	30	25	20	15	10
		Equivalent Chill Temperature								
3-6	5	48	43	37	32	27	22	16	11	6
7-10	10	40	34	28	22	16	10	4	-2	-9
11-15	15	36	29	22	16	9	2	-5	-11	-18
16-19	20	32	25	18	11	4	-3	-10	-17	-25
20-23	25	30	23	16	8	0	-7	-15	-22	-29
24-28	30	28	21	13	6	-2	-11	-18	-25	-33
29-32	35	27	19	11	4	-4	-12	-20	-27	-35
33-36	40	26	18	10	2	-6	-13	-21	-29	-37

B. Spring (March through May)

Early spring environmental conditions are similar to those of winter. Northwesterly winds continue to predominate but strong winds become less frequent after mid-season. Southeasterly winds occur with diminishing frequency as the season progresses, as low pressure systems track farther north and Scirocco events become less common.

Sea breezes start to occur during afternoons on warm days, but seldom exceed southeasterly 7 to 10 kt and pose no significant problem to harbor operations.

Spring temperatures start to moderate from those of winter, with temperatures normally ranging from about 50°F (10°C) to 66°F (19°C). Based on a 20-year record, the extreme range from the season is approximately 28°F (-2°C) to 86°F (30°C).

Precipitation amount and frequency gradually decrease as summer approaches.

C. Summer (June through September)

Summer weather at Cagliari brings few hazardous weather events. Northwesterly winds still predominate but are overcome during afternoon hours as the sea breeze mechanism takes effect. The southeasterly sea breeze starts about 1100L, seldom exceeds 7 to 10 kt, and is strongest between 1600L and 1700L. The sea breeze is usually not a problem to mariners. There is no land breeze at night.

Since summer Sciroccos are uncommon, and the storm track that brings low pressure systems south of Sardinia during the winter is displaced northward during the summer, strong southeasterly winds and associated waves are not usually a problem from June through September.

Summer temperatures normally range from about 64°F (18°C) to 82°F (28°C).

Summer is the driest season of the year, with July being the month of least precipitation.

D. Autumn (October)

The autumn season is short at Cagliari, as the transition from the summer weather regime to winter is quite abrupt. Strong northwesterly winds become more common by the end of the month as Mistral conditions return to the western Mediterranean Sea. Funneled to the Port through the Campidano Valley, the winds reach the Port as northwest 30 to 35 kt with gusts as strong as 60 to 70 kt. The winds cause only minor problems in the harbor, but anchor dragging is possible for vessels anchored in the harbor or south of Scoglio Sant' Elia. Because the wind is offshore, the fetch is severely limited and the effect on the sea surface is limited to a chop. The chop can, however, affect small craft operations in the harbor and jeopardize small boat runs to and from the anchorage. The wind is strongest when a low pressure system moves across the Gulf of Genoa.

Scirocco conditions commonly occur in autumn, and low pressure systems once again pass south of Sardinia as the storm track is displaced southward as the season progresses. Both events cause southeasterly flow to impact Cagliari harbor operations. Although the winds seldom exceed 30 kt and have a normal duration of only 24 to 36 hours, the long fetch southeast of Cagliari allows a significant swell to be generated. Section 3.5A contains a discussion of the effect of the southeasterly winds at Cagliari.

Autumn visibility is generally good, but early morning fog occasionally restricts visibility.

Temperatures begin to decrease from the warm values of summer. The normal daily range is approximately 57°F (14°C) to 73°F (23°C), but a 20-year record shows an extreme range of about 32°F (0°C) to 102°F (39°C).

October brings a sharp increase in precipitation, from that of the relatively dry summer months, as extratropical storm systems and their associated frontal systems transit the area. Scirocco events also bring warm rain, which may have a red color due to the sand and dust being transported northward from Africa.

E. Tropical Storm Season

Storms having tropical cyclone characteristics with fully developed eyes have been observed on at least three occasions in the Mediterranean basin: 23-26 September 1969, 22-28 January 1982, and 26-30 September 1983. On the latter occasion the storm moved northwest from the Gulf of Gabes (on the southeast coast of Tunisia), through the Strait of Sicily, along the east coast of Sardinia, and into the Gulf of Genoa. Winds of 100 kt were observed near the eye while Cagliari reported winds of 60 kts. The potential for another storm of this type to strike Cagliari is real and the meteorologist must be aware of the possibility.

3.6 Harbor Protection

While parts of the Port of Cagliari are well protected from specific hazardous conditions, there is exposure to others. The following sections address the various conditions and their effects on harbor operations.

3.6.1 Wind and weather

With one major exception, the topography of Sardinia protects the port area from most winds from west-southwest clockwise through east. The exception is wind that blows from the northwest through the Campidano Valley. Cagliari lies at the southeast end of the valley, and wind, usually of Mistral origin, funnels uninterrupted to the port. The major impact on harbor operations is primarily limited to small craft operations to and from the anchorage south of Scoglio Sant' Elia and to anchored vessels due to the possibility of anchor dragging.

Winds from east-southeast clockwise through southwest are unimpeded by any terrain effects and arrive at Cagliari with little change in their open sea direction or velocity except that southwesterly winds reach the harbor as southeast due to the configuration of the terrain around the port area. The direct effects of the wind alone may cause anchor dragging and curtailment of small boat operations outside the breakwaters surrounding the outer harbor. Rain and/or occasional thunderstorms may accompany southeasterly winds but have little impact on harbor operations.

3.6.2 Waves

The breakwater enclosed inner and outer harbors of the Port of Cagliari are well protected from significant wave action from all directions. The strong northwesterly wind which is funneled to the Port area through the Campidano Valley creates a chop, but the chop impacts only small boat operations. A southeasterly wind can generate a sea and swell that is potentially hazardous to vessels in the roadstead, but the impact inside the breakwaters is limited to waves which reflect off of the face of the breakwater (Molo Settentrionale) that protects the eastern side of the new commercial harbor being constructed west of the original harbor. The reflected waves pass through the harbor entrance and create difficult conditions for small boat operations within the harbor. The anchorages outside the breakwaters are exposed to the full force of the southeasterly swell.

Table 3-2 provides the shallow water wave conditions at the two designated points when deep water swell enters the harbor.

> Example: Use of Table 3-2.
>
> For a deep water wave condition of:
>
> 10 feet, 12 seconds, from 210°
>
> The approximate shallow water wave conditions are:
>
> Point 1: 3 feet, 12 seconds, from 170°
> Point 2: 5 feet, 12 seconds, from 185°

Table 3-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 3-3 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

CAGLIARI POINT 1:

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	100°	105°	110°	110°	115°	120°
	.7	.6	.7	.4	.4	.4
120°	120°	120°	120°	125°	125°	125°
	.9	.8	.8	.7	.6	.6
150°	150°	150°	145°	140°	140°	140°
	.9	.8	.7	.7	.6	.6
180°	180°	175°	170°	160°	160°	150°
	.9	.8	.6	.6	.7	.8
210°	190°	190°	180°	170°	165°	160°
	.6	.5	.4	.3	.3	.2
240°	180°	180°	180°	175°	170°	165°
	.2	.2	.3	.3	.4	.3

CAGLIARI POINT 2:

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	090°	090°	095°	100°	100°	100°
	.9	.8	.7	.5	.5	.5
120°	120°	120°	120°	120°	120°	120°
	1.0	.9	.9	.8	.8	.8
150°	150°	150°	145°	140°	140°	135°
	1.0	.9	.8	.7	.8	.8
180°	180°	175°	170°	160°	155°	150°
	1.0	.8	.8	.6	.5	.5
210°	210°	200°	190°	185°	180°	160°
	.7	.5	.4	.5	.5	.3
240°	180°	180°	205°	180°	170°	170°
	.2	.2	.2	.2	.3	.4

Situation specific shallow water wave conditions resulting from deep water wave propagation are given in Table 3-2 while the seasonal climatology of wave conditions in the harbor resulting from the propagation of deep water waves into the harbor are given in Table 3-3. If the actual or forecast deep water wave conditions are known, the expected conditions at the two specified harbor anchorage areas can be determined from Table 3-2. The mean duration of the condition, based on the shallow water wave heights, can be obtained from Table 3-3.

Example: Use of Tables 3-2 and 3-3.

The forecast for wave conditions tomorrow (winter case) outside the harbor are:

9 feet, 12 seconds, from 180°

Expected shallow water conditions and duration:

	Point 1	Point 2
height	5-6 feet	5-6 feet
period	12 seconds	12 seconds
direction	from 160°	from 160°
duration	13 hours	13 hours

Interpretation of the information from Tables 3-2 and 3-3 provide guidance on the local wave conditions expected tomorrow at the various harbor points. The duration values are mean values for the specified height range and season. Knowledge of the current synoptic pattern and forecast/expected duration should be used when available.

Possible applications to small boat operations are; selection of the mother ships anchorage point and/or areas of small boat work. The condition duration information provides insight as to how long before a change can be expected. The local wave direction information could be of use in selecting anchorage configuration and related small boat operations.

Table 3-3. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 feet and greater than 6.6 feet by climatological season.

CAGLIARI POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	20	10	7	11
Average Duration (hrs)	13	13	10	10
Period Max Energy (sec)	12	8	8	8
>6.6 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	5	2	1	1
Average Duration (hrs)	8	6	8	8
Period Max Energy (sec)	12	12	12	12*

CAGLIARI POINT 2:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	20	10	7	13
Average Duration (hrs)	13	11	12	11
Period Max Energy (sec)	9-10	8-9	8	8
>6.6 feet	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	2	1	1
Average Duration (hrs)	9	8	6	9
Period Max Energy (sec)	10	12	12	9-10

* The 12 second period shows a sharp peak in the wave climatology energy values. This indicates that for heights over 6.6 feet, waves with a 12 second period have a high frequency of occurrence. This pattern is known as "short crested conditions" (see page A-3 of Appendix A for explanation of "short crested conditions").

Local wind wave conditions are provided in Table 3-4 for Cagliari point 1. The specified fetch lengths are specifically for point 1. The time to reach the fetch limited height assumes an initial flat ocean. With a pre-existing wave height, the times are shorter.

Table 3-4. Gulf of Cagliari point 1. Local wind waves for fetch limited conditions related to point 1 (based on JONSWAP model).

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
SW 12 n mi	2-3/4 2	3/4 2	3-4/4 1-2	4-5/4-5 2	5-6/5 2
NW 7 n mi	<2 ft	2/3 1	3/4 1	3-4/4 1	4/4 1
N 4 n mi	<2 ft	<2 ft	2/3 1	2-3/3 1	3/3 1
E 10 n mi	2/3-4 1-2	3/3-4 2	3-4/4 2	4/4-5 1-2	5/5 1-2
SE* 16 n mi	3/4 3	3-4/4-5 2	4/5 2	4-5/5 2	6/5 2

* Southwest flow over the open sea backs to southeast over the Gulf of Cagliari. The maximum fetch resulting from such a wind pattern would be about 16 n mi. Wind waves would be generated over that distance and combine with the deep water swell which changes from southwest to south over the Gulf (see Table 3-3).

Example: Small boat wave forecasts (based on the assumption that swell is not a limiting condition).

Forecast for Tomorrow:

Time	Wind (Forecast)	Waves (Table 3-4)
prior to 0700 LST	light and variable	< 1 ft
0700 to 1200	SW 8-10 kt	< 4 ft
1200 to 1500	SW 22-26 kt	3 ft at 4 sec by 1400
1500 to 2000	NW 28-32 kt	3 ft at 4 sec by 1600-1700
2000 to 2200	NW 14-18 kt	less than 2 ft by 2100

Interpretation: Assuming that the limiting factor is waves greater than 3 feet, small boat operations would become marginal by 1400 and remain so until 2000-2100.

Combined wave heights are computed by finding the square root of the sum of the squares of the wind wave and swell heights. For example, if the wind waves were 3 ft and the swell 8 ft the combined height would be about 8.5 ft.

$$\sqrt{3^2 + 8^2} = \sqrt{9 + 64} = \sqrt{73} \approx 8.5$$

Note that the increased height is relatively small. Even if the two wave types were of equal height the combined heights are only 1.4 times the equal height. In cases where one or the other heights are twice that of the other, the combined height will only increase over the larger of the two by 1.12 times (10 ft swell and 5 ft wind wave combined results in 11.2 ft height).

3.6.3 Wave data uses and considerations

Local wind waves build up quite rapidly and also decrease rapidly when winds subside. The period and therefore length of wind waves is generally short relative to the period and length of waves propagated into the harbor (see Appendix A). The shorter period and length result in wind waves being characterized by choppy conditions. When wind waves are superimposed on deep water waves propagated into shallow water, the waves can become quite complex and confused. Under such conditions, when more than one source of waves is influencing a location, tending or joint operations can be hazardous even if the individual wave train heights are not significantly high. Vessels of various lengths may respond in different motions to the different wave lengths present. The information on wave periods, provided in various tables, should be considered when forecasts are made for joint operations of various length vessels.

Wind waves will seldom be a problem for the ships. Under strong northwest flow wind waves may make small boat operations somewhat hazardous from either anchorage point. Vessels should anchor in as close as possible to reduce the offshore fetch length. The strong winds will present a greater threat than the wind waves and may require ships to sortie.

3.7 Protective and Mitigating Measures

3.7.1 Moving to new anchorage

Vessels desiring to avoid strong northwesterly winds can move east around Cape Carbonara and north along the east coast of Sardinia to the north of Cape Ferrato. Ships are advised to leave the anchorage and move to open sea when heavy southeast swell is occurring or forecast.

The Gulf of Palmas (Golfo di Palmas), located about 40 n mi west of Cagliari, offers good protection from any north wind (usually not a problem at Cagliari), and southeasterly winds and swell.

3.7.2 Sortie/remain in port

Vessels moored in the protected area inside the breakwaters should not find it necessary to sortie under any situation short of a tropical cyclone. Units should remain at their piers, doubling lines where necessary.

All vessels should put to sea and evade the storm if a tropical cyclone is forecast to affect Cagliari.

3.7.3 Scheduling

On average, wind velocities will be lighter during early morning hours than during the late afternoon. If possible, evolutions such as arriving, departing, or changing berths should be scheduled to avoid peak wind hours.

3.8 Local indicators of Hazardous Weather Conditions

Strong winds from the northwest and southeast, and heavy swell from the southeast pose the greatest threats to the Port of Cagliari.

Northwesterly Wind - Since most of the strong northwesterly winds at Cagliari are caused by Mistral winds originating in the Gulf of Lion, they should be anticipated at Cagliari about 24 hours after a strong Mistral has commenced in that area. A 5 to 7 hour advance warning of strong northwest flow is indicated whenever orographically induced clouds build on the mountains west of the port.

Scirocco/Southeasterly Wind and Swell - Scirocco winds occur mainly during autumn. A 24-hour advance warning of an impending Scirocco is provided when the typical hazy atmosphere becomes clear and the visibility between the harbor at Cagliari and the anchorage at Sarroch is unlimited. Also, a mass of clouds on the mountains near Sarroch is an indication of southeasterly flow and impending southeasterly winds and swell. During winter, a Scirocco with rain is indicated in 24-hours if the sun "turns white."

Tanker crews at Sarroch sometimes call the weather office at the Cagliari Airport to check on the local weather forecast when they start to feel swell motion in the anchorage. The onset of such swell motion is an indicator of impending southeasterly winds since the long-period swell often travels faster than the wind field that generated it, and arrives ahead of the winds.

Southeasterly wind and swell is also caused by low pressure systems which transit eastward south of Sardinia, so they should be anticipated anytime a low moves eastward between Sardinia and the North African coast.

TABLE 3-5. Potential problem situations at Port of Cagliari - ALL SEASONS

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
1. Moored. Winter Spring Uncommon Summer Autumn	a. Strong northwesterly wind - Usually resulting from a Mistral, with the winds funneled through the Campidano Valley. Decreasing intensity and frequency April through September. A strong event may have 30-35 kts with gusts to 60-70 kts, most likely in late winter and early spring but possible by the end of October. Because of a near zero fetch length, wind raises only a chop in the harbor and anchorage. Wind can create difficult ship handling in inner harbor due to restricted room and slow headway.	a. Remain at mooring, doubling mooring lines if a strong event is forecast. Secure loose gear. Minimize personnel exposure on weather decks.	a. Northwesterly winds should be anticipated about 24-hours after a Mistral has started in the Gulf of Lion, with the velocity of the wind dependent on the Mistral strength. Mistral frequency and intensity decrease April Through September. A buildup of orographically induced cumulus clouds over the mountains west of the port indicates the onset of northwesterly winds at Cagliari in 5-7 hours.
Winter Spring Uncommon Summer Autumn	b. Southeasterly winds/seas - Caused by a Scirocco or low pressure system passing south of Sardinia, phenomena least common in summer increasing frequency starting in October. Winds to 30 kts may last for 24-36 hours and raise a swell which is hazardous for ships in the anchorages, with the worse effects felt at the Sarroch Anchorage. Incoming or departing vessels may experience ship handling problems in the inner harbor.	b. Remain at mooring, doubling mooring lines if strong winds are forecast. Secure loose gear. Minimize personnel exposure on weather decks. Swell should not impact inner harbor operations.	b. A 24-hour advance warning of Scirocco winds is indicated when haze clears and good visibility prevails between Cagliari and the Sarroch anchorage. A buildup of clouds on the mountains west of Sarroch is an indication of southeasterly flow and possible forthcoming strong southeasterly winds and seas. Tanker crews from vessels in the Sarroch anchorage sometimes telephone the weather office at Cagliari Airport when they start to feel swell motion. Since long period swell often travels faster than the wind field that generated the swell, the calls provide warning of impending strong southeasterly winds.
Winter Spring Summer Autumn	c. Tropical cyclone - Not a common phenomena in the Mediterranean region, but when occurring, have a strong likelihood of occurring in late summer or autumn. Two of three storms recorded since 1969 have occurred in late September, with one having maximum winds of 100 kts and causing sustained 60 kt winds at Cagliari.	c. Because of the potential for destruction, mariners should make every effort to avoid being placed in the path of a tropical cyclone. Vessels should put to sea and take evasive action at the first indication that a tropical cyclone may strike or pass close to Cagliari.	c. There is little advance indication of the formation of a tropical cyclone in the Mediterranean. Close monitoring of satellite images and synoptic reports is necessary for early detection. An approaching tropical cyclone may be indicated by noting high, thin clouds in cyclonically spiralling, gradually thickening bands, or unexplained long-period swell approaching from the southern semicircle.
2. Anchored. Winter Spring Uncommon Summer Autumn	a. Strong northwesterly wind - Usually resulting from a Mistral, with the winds funneled through the Campidano Valley. Decreasing intensity and frequency April through September. A strong event may have 30-35 kts with gusts to 60-70 kts, most likely in late winter and early spring but possible by the end of October. Because of a near zero fetch length, wind raises only a chop in the harbor and anchorage. Wind can create difficult ship handling in inner harbor due to restricted room and slow headway.	a. Remain at anchorage, deploying two anchors if necessary to avoid anchor dragging. If a very strong event makes remaining at the anchorage inadvisable, moving to the east side of Sardinia north of Cape Ferrato will provide protection from the winds.	a. Northwesterly winds should be anticipated about 24-hours after a Mistral has started in the Gulf of Lion, with the velocity of the wind dependent on the Mistral strength. Mistral frequency and intensity decrease April Through September. A buildup of orographically induced cumulus clouds over the mountains west of the port indicates the onset of northwesterly winds at Cagliari in 5-7 hours.
Winter Spring Uncommon Summer Autumn	b. Southeasterly winds/seas - Caused by a Scirocco or low pressure system passing south of Sardinia, phenomena least common in summer increasing frequency starting in October. Winds to 30 kts may last for 24-36 hours and raise a swell which is hazardous for ships in the anchorages, with the worse effects felt at the Sarroch Anchorage. Incoming or departing vessels may experience ship handling problems in the inner harbor.	b. Leaving the anchorage is recommended if a strong event is forecast. The Gulf of Palmas (Golfo di Palmas), approximately 40 n mi west of Cagliari, provides good protection from southeasterly winds and seas.	b. A 24-hour advance warning of Scirocco winds is indicated when haze clears and good visibility prevails between Cagliari and the Sarroch anchorage. A buildup of clouds on the mountains west of Sarroch is an indication of southeasterly flow and possible forthcoming strong southeasterly winds and seas. Tanker crews from vessels in the Sarroch anchorage sometimes telephone the weather office at Cagliari Airport when they start to feel swell motion. Since long period swell often travels faster than the wind field that generated the swell, the calls provide warning of impending strong southeasterly winds.
Winter Spring Summer Autumn	c. Tropical cyclone - Not a common phenomena in the Mediterranean region, but when occurring, have a strong likelihood of occurring in late summer or autumn. Two of three storms recorded since 1969 have occurred in late September, with one having maximum winds of 100 kts and causing sustained 60 kt winds at Cagliari.	c. Because of the potential for destruction, mariners should make every effort to avoid being placed in the path of a tropical cyclone. Vessels should put to sea and take evasive action at the first indication that a tropical cyclone may strike or pass close to Cagliari.	c. There is little advance indication of the formation of a tropical cyclone in the Mediterranean. Close monitoring of satellite images and synoptic reports is necessary for early detection. An approaching tropical cyclone may be indicated by noting high, thin clouds in cyclonically spiralling, gradually thickening bands, or unexplained long-period swell approaching from the southern semicircle.

TABLE 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
3. Arriving/departing. Winter Spring Uncommon Summer Autumn	a. Strong northwesterly wind - Usually resulting from a Mistral, with the winds funneled through the Campidano Valley. Decreasing intensity and frequency April through September. A strong event may have 30-35 kts with gusts to 60-70 kts, most likely in late winter and early spring but possible by the end of October. Because of a near zero fetch length, wind raises only a chop in the harbor and anchorage. Wind can create difficult ship handling in inner harbor due to restricted room and slow headway.	a. Due to restricted maneuvering room and slow headway in the harbor, vessels inbound to the inner harbor should consider remaining outside the harbor area if strong winds are blowing. Outbound vessels should revise departure plans as necessary to avoid the strongest winds.	a. Northwesterly winds should be anticipated about 24-hours after a Mistral has started in the Gulf of Lion, with the velocity of the wind dependent on the Mistral strength. Mistral frequency and intensity decrease April Through September. A buildup of orographically induced cumulus clouds over the mountains west of the port indicates the onset of northwesterly winds at Cagliari in 5-7 hours.
Winter Spring Uncommon Summer Autumn	b. Southeasterly winds/seas - Caused by a Scirocco or low pressure system passing south of Sardinia, phenomena least common in summer increasing frequency starting in October. Winds to 30 kts may last for 24-36 hours and raise a swell which is hazardous for ships in the anchorages, with the worse effects felt at the Sarroch Anchorage. Incoming or departing vessels may experience ship handling problems in the inner harbor.	b. Strong southeasterly winds may cause ship handling problems in the inner harbor due to restricted maneuvering room and slow headway. Vessels outside the southern breakwater (Nuovo Molo di Levante) will be exposed to the full force of the wind and swell. Since strong southeasterly winds seldom last longer than 24-36 hours, vessels are advised to remain in port/at sea and delay departure/arrival until conditions abate.	b. A 24-hour advance warning of Scirocco winds is indicated when haze clears and good visibility prevails between Cagliari and the Sarroch anchorage. A buildup of clouds on the mountains west of Sarroch is an indication of southeasterly flow and possible forthcoming strong southeasterly winds and seas. Tanker crews from vessels in the Sarroch anchorage sometimes telephone the weather office at Cagliari Airport when they start to feel swell motion. Since long period swell often travels faster than the wind field that generated the swell, the calls provide warning of impending strong southeasterly winds.
Winter Spring Summer Autumn	c. Tropical cyclone - Not a common phenomena in the Mediterranean region, but when occurring, have a strong likelihood of occurring in late summer or autumn. Two of three storms recorded since 1969 have occurred in late September, with one having maximum winds of 100 kts and causing sustained 60 kt winds at Cagliari.	c. Because of the potential for destruction, mariners should make every effort to avoid being placed in the path of a tropical cyclone. Vessels should put to sea and take evasive action at the first indication that a tropical cyclone may strike or pass close to Cagliari.	c. There is little advance indication of the formation of a tropical cyclone in the Mediterranean. Close monitoring of satellite images and synoptic reports is necessary for early detection. An approaching tropical cyclone may be indicated by noting high, thin clouds in cyclonically spiralling, gradually thickening bands, or unexplained long-period swell approaching from the southern semicircle.
4. Small boat operations. Winter Spring Uncommon Summer Autumn	a. Strong northwesterly wind - Usually resulting from a Mistral, with the winds funneled through the Campidano Valley. Decreasing intensity and frequency April through September. A strong event may have 30-35 kts with gusts to 60-70 kts, most likely in late winter and early spring but possible by the end of October. Because of a near zero fetch length, wind raises only a chop in the harbor and anchorage. Wind can create difficult ship handling in inner harbor due to restricted room and slow headway.	a. Small craft should encounter little difficulty in the inner and most of the outer harbor in all but the strongest winds. Boats operating near the outer harbor entrance and outside the breakwaters may have to curtail operations due to the chop raised by the wind.	a. Northwesterly winds should be anticipated about 24-hours after a Mistral has started in the Gulf of Lion, with the velocity of the wind dependent on the Mistral strength. Mistral frequency and intensity decrease April Through September. A buildup of orographically induced cumulus clouds over the mountains west of the port indicates the onset of northwesterly winds at Cagliari in 5-7 hours.
Winter Spring Uncommon Summer Autumn	b. Southeasterly winds/seas - Caused by a Scirocco or low pressure system passing south of Sardinia, phenomena least common in summer increasing frequency starting in October. Winds to 30 kts may last for 24-36 hours and raise a swell which is hazardous for ships in the anchorages, with the worse effects felt at the Sarroch Anchorage. Incoming or departing vessels may experience ship handling problems in the inner harbor.	b. Small craft in the inner and most of the outer harbor should be essentially unaffected by the direct effect of winds and seas. Boats operating outside the waters protected by the breakwaters and going to/from the anchorages may have to curtail operations until the seas abate. Wave reflection off of the face of the breakwater protecting the east side of the new commercial port may create a chop north of Nuovo Molo di Levante that could make small boat operation hazardous in the outer harbor entrance.	b. A 24-hour advance warning of Scirocco winds is indicated when haze clears and good visibility prevails between Cagliari and the Sarroch anchorage. A buildup of clouds on the mountains west of Sarroch is an indication of southeasterly flow and possible forthcoming strong southeasterly winds and seas. Tanker crews from vessels in the Sarroch anchorage sometimes telephone the weather office at Cagliari Airport when they start to feel swell motion. Since long period swell often travels faster than the wind field that generated the swell, the calls provide warning of impending strong southeasterly winds.
Winter Spring Summer Autumn	c. Tropical cyclone - Not a common phenomena in the Mediterranean region, but when occurring, have a strong likelihood of occurring in late summer or autumn. Two of three storms recorded since 1969 have occurred in late September, with one having maximum winds of 100 kts and causing sustained 60 kt winds at Cagliari.	c. All small boat operations should cease at the approach of the tropical cyclone. Small craft should be hoisted out of the water and secured on deck or, in the case of shore based boats, well above the high tide line.	c. There is little advance indication of the formation of a tropical cyclone in the Mediterranean. Close monitoring of satellite images and synoptic reports is necessary for early detection. An approaching tropical cyclone may be indicated by noting high, thin clouds in cyclonically spiralling, gradually thickening bands, or unexplained long-period swell approaching from the southern semicircle.

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PORT VISIT INFORMATION

JUNE 1985. NEPRF meteorologists R. Fett and R. Picard met with Port Captain CAPT Battaglia and Italian Weather Service meteorologists MAJ Ielo and CAPT Torchiani to obtain much of the information included in this port evaluation.

APPENDIX A

General Purpose Oceanographic Information

This section provides general information on wave forecasting and wave climatology as used in this study. The forecasting material is not harbor specific. The material in paragraphs A.1 and A.2 was extracted from H.O. Pub. No. 603, Practical Methods for Observing and Forecasting Ocean Waves (Pierson, Neumann, and James, 1955). The information on fully arisen wave conditions (A.3) and wave conditions within the fetch region (A.4) is based on the JONSWAP model. This model was developed from measurements of wind wave growth over the North Sea in 1973. The JONSWAP model is considered more appropriate for an enclosed sea where residual wave activity is minimal and the onset and end of locally forced wind events occur rapidly (Thornton, 1986), and where waves are fetch limited and growing (Hasselmann, et al., 1976). Enclosed sea, rapid onset/subsiding local winds, and fetch limited waves are more representative of the Mediterranean waves and winds than the conditions of the North Atlantic from which data was used for the Pierson and Moskowitz (P-M) Spectra (Neumann and Pierson 1966). The P-M model refined the original spectra of H.O. 603, which over developed wave heights.

The primary difference in the results of the JONSWAP and P-M models is that it takes the JONSWAP model longer to reach a given height or fully developed seas. In part this reflects the different starting wave conditions. Because the propagation of waves from surrounding areas into semi-enclosed seas, bays, harbors, etc. is limited, there is little residual wave action following periods of locally light/calm winds and the sea surface is nearly flat. A local wind developed wave growth is therefore slower than wave growth in the open ocean where some residual wave action is generally always present. This slower wave development is a built in bias in the formulation of the JONSWAP model which is based on data collected in an enclosed sea.

A.1 Definitions

Waves that are being generated by local winds are called "SEA". Waves that have traveled out of the generating area are known as "SWELL". Seas are chaotic in period, height and direction while swell approaches a simple sine wave pattern as its distance from the generating area increases. An in-between state exists for a few hundred miles outside the generating area and is a condition that reflects parts of both of the above definitions. In the Mediterranean area, because its fetches and open sea expanses are limited, SEA or IN- BETWEEN conditions will prevail. The "SIGNIFICANT WAVE HEIGHT" is defined as the average value of the heights of the one-third highest waves. PERIOD and WAVE LENGTH refer to the time between passage of, and distances between, two successive crests on the sea surface. The FREQUENCY is the reciprocal of the period ($f = 1/T$) therefore as the period increases the frequency decreases. Waves result from the transfer of energy from the wind to the sea surface. The area over which the wind blows is known as the FETCH, and the length of time that the wind has blown is the DURATION. The characteristics of waves (height, length, and period) depend on the duration, fetch, and velocity of the wind. There is a continuous generation of small short waves from the time the wind starts until it stops. With continual transfer of energy from the wind to the sea surface the waves grow with the older waves leading the growth and spreading the energy over a greater range of frequencies. Throughout the growth cycle a SPECTRUM of ocean waves is being developed.

A.2 <u>Wave Spectrum</u>

Wave characteristics are best described by means of their range of frequencies and directions or their spectrum and the shape of the spectrum. If the spectrum of the waves covers a wide range of frequencies and directions (known as short-crested conditions), SEA conditions prevail. If the spectrum covers a narrow range of frequencies and directions (long crested conditions), SWELL conditions prevail. The wave spectrum depends on the duration of the wind, length of the fetch, and on the wind velocity. At a given wind speed and a given state of wave development, each spectrum has a band of frequencies where most of the total energy is concentrated. As the wind speed increases the range of significant frequencies extends more and more toward lower frequencies (longer periods). The frequency of maximum energy is given in equation 1.1 where v is the wind speed in knots.

$$f_{max} = \frac{2.476}{v} \qquad (1.1)$$

The wave energy, being a function of height squared, increases rapidly as the wind speed increases and the maximum energy band shifts to lower frequencies. This results in the new developing smaller waves (higher frequencies) becoming less significant in the energy spectrum as well as to the observer. As larger waves develop an observer will pay less and less attention to the small waves. At the low frequency (high period) end the energy drops off rapidly, the longest waves are relatively low and extremely flat, and therefore also masked by the high energy frequencies. The result is that 5% of the upper frequencies and 3% of the lower frequencies can be cut-off and only the remaining frequencies are considered as the <u>"significant part of the wave spectrum"</u>. The resulting range of significant frequencies or periods are used in defining a fully arisen sea. For a fully arisen sea the approximate average period for a given wind speed can be determined from equation (1.2).

$$\bar{T} = 0.285v \tag{1.2}$$

Where v is wind speed in knots and T is period in seconds. The approximate average wave length in a fully arisen sea is given by equation (1.3).

$$\bar{L} = 3.41\ \bar{T}^2 \tag{1.3}$$

Where $\bar{L}$ is average wave length in feet and $\bar{T}$ is average period in seconds.

The approximate average wave length of a fully arisen sea can also be expressed as:

$$\bar{L} = .67\text{"L"} \tag{1.4}$$

where "L" = $5.12T^2$, the wave length for the classic sine wave.

A.3 <u>Fully Arisen Sea Conditions</u>

For each wind speed there are minimum fetch (n mi) and duration (hr) values required for a fully arisen sea to exist. Table A-1 lists minimum fetch and duration values for selected wind speeds, values of significant wave (average of the highest 1/3 waves) period and height, and wave length of the average wave during developing and fully arisen seas. The minimum duration time assumes a start from a flat sea. When pre-existing lower waves exist the time to fetch limited height will be shorter. Therefore the table duration time represents the maximum duration required.

Table A-1. Fully Arisen Deep Water Sea Conditions Based on the JONSWAP Model.

Wind Speed (kt)	Minimum Fetch/Duration (n mi) (hrs)	Sig Wave (H1/3) Period/Height (sec) (ft)	Wave Length (ft)[1,2] Developing/Fully /Arisen L X (.5) /L X (.67)
10	28 / 4	4 / 2	41 / 55
15	55 / 6	6 / 4	92 / 123
20	110 / 8	8 / 8	164 / 220
25	160 / 11	9 / 12	208 / 278
30	210 / 13	11 / 16	310 / 415
35	310 / 15	13 / 22	433 / 580
40	410 / 17	15 / 30	576 / 772

NOTES:

[1] Depths throughout fetch and travel zone must be greater than 1/2 the wave length, otherwise shoaling and refraction take place and the deep water characteristics of waves are modified.

[2] For the classic sine wave the wave length (L) equals 5.12 times the period (T) squared ($L = 5.12T^2$). As waves develop and mature to fully developed waves and then propagate out of the fetch area as swell their wave lengths approach the classic sine wave length. Therefore the wave lengths of developing waves are less than those of fully developed waves which in turn are less than the length of the resulting swell. The factor of .5 (developing) and .67 (fully developed) reflect this relationship.

A.4 Wave Conditions Within The Fetch Region

Waves produced by local winds are referred to as SEA. In harbors the local sea or wind waves may create hazardous conditions for certain operations. Generally within harbors the fetch lengths will be short and therefore the growth of local wind waves will be fetch limited. This implies that there are locally determined upper limits of wave height and period for each wind velocity. Significant changes in speed or direction will result in generation of a new wave group with a new set of height and period limits. Once a fetch limited sea reaches its upper limits no further growth will occur unless the wind speed increases.

Table A-2 provides upper limits of period and height for given wind speeds over some selected fetch lengths. The duration in hours required to reach these upper limits (assuming a start from calm and flat sea conditions) is also provided for each combination of fetch length and wind speed. Some possible uses of Table A-2 information are:

1) If the only waves in the area are locally generated wind waves, the Table can be used to forecast the upper limit of sea conditions for combinations of given wind speeds and fetch length.

2) If deep water swell is influencing the local area in addition to locally generated wind waves, then the Table can be used to determine the wind waves that will combine with the swell. Shallow water swell conditions are influenced by local bathymetry (refraction and shoaling) and will be addressed in each specific harbor study.

3) Given a wind speed over a known fetch length the maximum significant wave conditions and time needed to reach this condition can be determined.

Table A-2. Fetch Limited Wind Wave Conditions and Time Required to Reach These Limits (Based on JONSWAP Model). Enter the table with wind speed and fetch length to determine the significant wave height and period, and time duration needed for wind waves to reach these limiting factors. All of the fetch/speed combinations are fetch limited except the 100 n mi fetch and 18 kt speed.

<u>Format:</u> height (feet)/period (seconds)
duration required (hours)

Fetch Length (n mi) \ Wind Speed (kt)	18	24	30	36	42
10	2/3-4 1-2	3/3-4 2	3-4/4 2	4/4-5 1-2	5/5 1-2
20	3/4-5 2-3	4/4-5 3	5/5 3	6/5-6 3-4	7/5-6 3
30	3-4/5 3	5/5-6 4	6/6 3-4	7/6 3-4	8/6-7 3
40	4-5/5-6 4-5	5/6 4	6-7/6-7 4	8/7 4	9-10/7-8 3-4
100	5/6-7[1] 5-6	9/8 8	11/9 7	13/9 7	15-16/9-10 7

[1] 18 kt winds are not fetch limited over a 100 n mi fetch.

An example of expected wave conditions based on Table A-2 follows:

<u>WIND FORECAST OR CONDITION</u>

An offshore wind of about 24 kt with a fetch limit of 20 n mi (ship is 20 n mi from the coast) is forecast or has been occurring.

<u>SEA FORECAST OR CONDITION</u>

From Table A-2: If the wind condition is forecast to last, or has been occurring, for at least 3 hours:

Expect sea conditions of 4 feet at 4-5 second period to develop or exist. If the condition lasts less than 3 hours the seas will be lower. If the condition lasts beyond 3 hours the sea will not grow beyond that developed at the end of about 3 hours unless there is an increase in wind speed or a change in the direction that results in a longer fetch.

A.5 Wave Climatology

The wave climatology used in these harbor studies is based on 11 years of Mediterranean SOWM output. The MED-SOWM is discussed in Volume II of the U.S. Naval Oceanography Command Numerical Environmental Products Manual (1986). A deep water MED-SOWM grid point was selected as representative of the deep water wave conditions outside each harbor. The deep water waves were then propagated into the shallow water areas. Using linear wave theory and wave refraction computations the shallow water climatology was derived from the modified deep water wave conditions. This climatology does not include the local wind generated seas. This omission, by design, is accounted for by removing all wave data for periods less than 6 seconds in the climatology. These shorter period waves are typically dominated by locally generated wind waves.

A.6 Propagation of Deep Water Swell Into Shallow Water Areas

When deep water swell moves into shallow water the wave patterns are modified, i.e., the wave heights and directions typically change, but the wave period remains constant. Several changes may take place including shoaling as the wave feels the ocean bottom, refraction as the wave crest adjusts to the bathymetry pattern, changing so that the crest becomes more parallel to the bathymetry contours, friction with the bottom sediments, interaction with currents, and adjustments caused by water temperature gradients. In this work, only shoaling and refraction effects are considered. Consideration of the other factors are beyond the resources available for this study and, furthermore, they are considered less significant in the harbors of this study than the refraction and shoaling factors.

To determine the conditions of the deep water waves in the shallow water areas the deep water conditions were first obtained from the Navy's operational MED-SOWM wave model. The bathymetry for the harbor/area of interest was extracted from available charts and digitized for computer use. Figure A-1 is a sample plot of bathymetry as used in this project. A ray path refraction/shoaling program was run for selected combinations of deep water wave direction and period. The selection was based on the near deep water wave climatology and harbor exposure. Each study area requires a number of ray path computations. Typically there are 3 or 4 directions (at 30° increments) and 5 or 6 periods (at 2 second intervals) of concern for each area of study. This results in 15 to 24 plots per area/harbor. To reduce this to a manageable format for quick reference, specific locations within each study area were selected and the information was summarized and is presented in the specific harbor studies in tabular form.

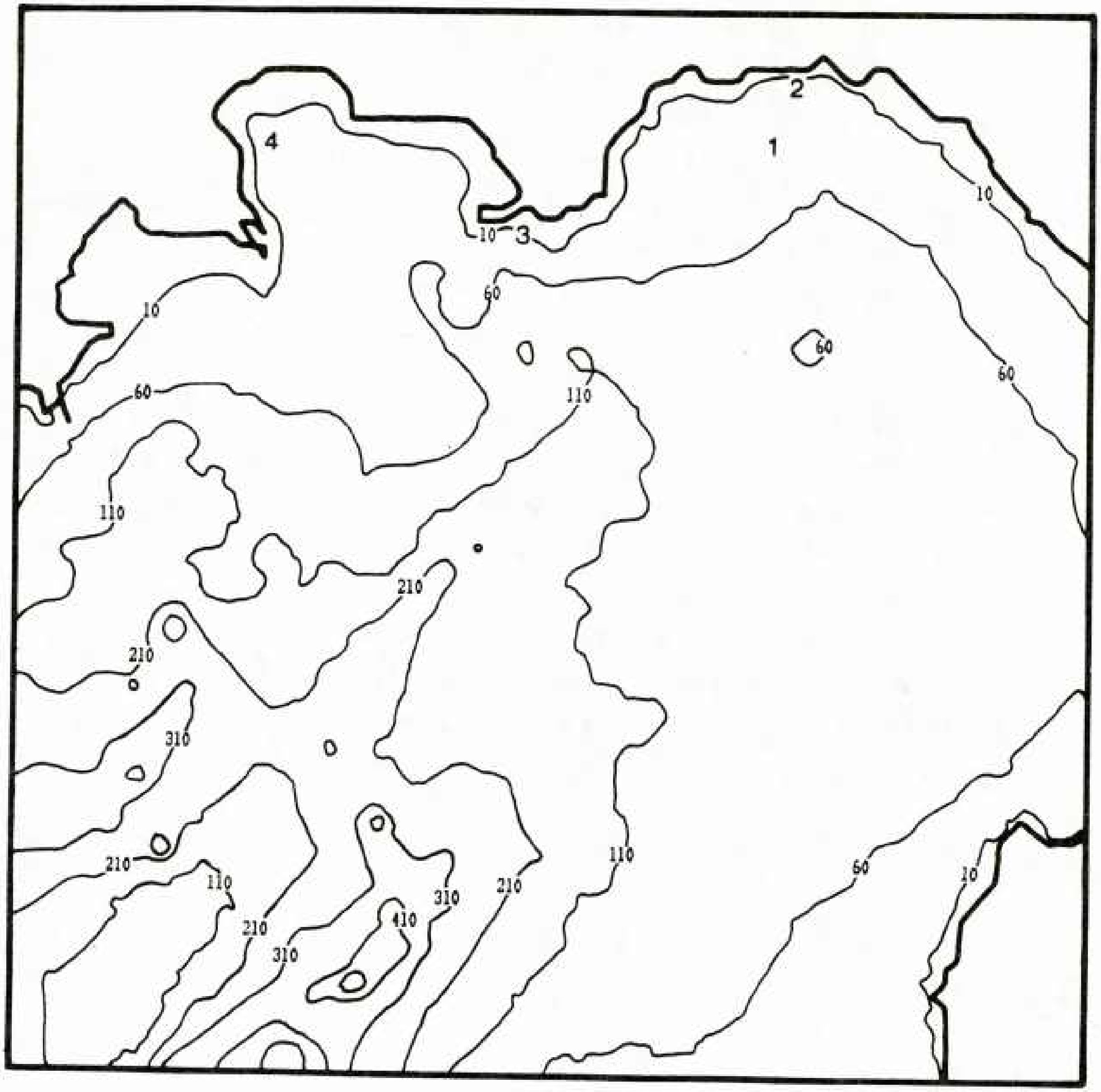

Figure A-1. Example plot of bathymetry (Naples harbor) as used in this project. For plotting purposes only, contours are at 50 fathom intervals from an initial 10 fathoms to 110 fathoms, and at 100 fathom intervals thereafter. The larger size numbers identify specific anchorage areas addressed in the harbor study.

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